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Human-Animal Trust as an Analog for Human-Robot Trust: A Review of Current Evidence

by Deborah R. Billings, Kristin E. Schaefer, Jessie Y. C. Chen, Vivien Kocsis, Maria Barrera, Jacquelyn Cook, Michelle Ferrer, and Peter A. Hancock

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14. ABSTRACT
Trust is an essential element required for effective human-robot teaming. Yet, experimental research examining human-robot trust in team interactions is at its infancy stage. Conducting empirical studies using live robots can be extremely difficult in terms of money, time, equipment programmability, and system support. Information in the area of human-robot trust is limited, but parallels can be drawn with trust in other domains of human-entity interactions, such as human-animal trust. Here we investigate the current evidence related to factors impacting trust in human-animal partnerships. Several of the outlined factors overlap with previously identified factors associated with trust in robots, supporting the notion that human-animal trust may be an appropriate analog for human-robot trust. Implications for future research are enumerated and discussed.

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Preface

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1. Introduction

Trust can be defined as "*the reliance by an agent that actions prejudicial to their well-being will not be undertaken by influential others"* (Hancock, Billings, and Schaefer, 2011a, p. 24). Trust is a critical component of human relationships because it impacts interaction outcomes such as attitudes, behaviors, and perceptions (Dirks and Ferrin, 2001). Trust is also an essential element required to ensure that any functional relationship between humans and non-human entities will ultimately be effective. While trust between human partners has been researched at length, there is growing interest in the nature of human trust in non-human partners, such as animals and robotic systems.

1.1 Human-Robot Trust

Robotic systems are advantageous primarily due to their ability to extend human capabilities and compensate for the limitations of humans, especially in extreme environments (Oleson et al., 2011). Robots have been placed in numerous roles in a variety of tasking environments, including transportation safety, space exploration, and military operations (Madhavan and Wiegmann, 2007; Li, Rau, and Li, 2010; Bluethmann et al., 2003; Freedy et al., 2007; Burke, et al., 2004; Kean, 2010; Jones and Schmidlin, 2011). The distinctive roles that these robots fill are based on their functional capabilities. Regardless of robotic domain, environment, or task, a human's trust in a robot is necessary for effective human-robot interaction (HRI) to occur. Ensuring appropriate levels of trust can be a particular challenge to the successful integration of robotic assets in human teams (Freedy et al., 2007). A triadic model of trust, which categorizes factors of trust as human, robot, or environmental characteristics, was previously developed and explored (Hancock et al., 2011b), see figure 1. However, due to the dearth of empirical literature specifically relating to human-robot trust, this descriptive model may not be completely comprehensive of all the factors that truly impact trust in these relationships. For this reason, research relating to other human-non-human entity relationships that are similar to human-robot partnerships can provide additional information that can be applied to our existing human-robot trust model.

It has been suggested that human-animal interactions may represent a suitable metaphor for human-robot interactions (Coeckelbergh, 2011). There have been numerous reports about the emotional attachments some users developed with their robots (Hsu, 2009; Singer, 2009; Sung et al., 2007). For example, some Soldiers formed such a strong bond with their explosive-disposal robots (e.g., PackBot,* TALON†) that they insist getting the same robot back after it is repaired or become sad if their damaged robot cannot be repaired (Hsu, 2009; Singer, 2009).

*PackBot is a trademark of iRobot Corporation.

†TALON is a trademark of Foster-Miller, Inc.

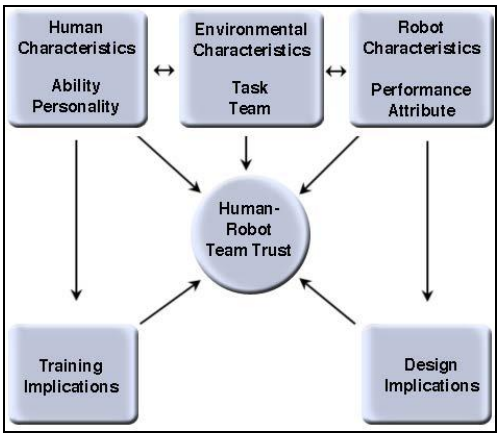

Figure 1. Triadic model of human-robot trust: Human, environmental, and robot factors.

Sung et al. (2007) reported that some Roomba* users felt that their work of tidying before using their Roomba was "a token of their appreciation for the hard cleaning work" that their robot did (Sung et al., 2007, p. 157). Furthermore, there seems to be similarities between how people anthropomorphize their pets and their robots (Kiesler, Lee, and Kramer, 2006; Kiesler et al., 2008; Sung et al., 2007). While animals are certainly not robots, the characteristics associated with trust in human-animal interactions may in fact extend to the realm of HRI.

1.2 Human-Animal Trust

Animals have been domesticated for various reasons, and a human's relationship with them depends on the context of the interaction and the roles in which the animals are placed (Coeckelbergh, 2011). Human-animal relationships represent a unique form of partnership which can often directly benefit the human physically, emotionally, and cognitively (Wilson, 1994). There are four primary types of partnerships that exist: companionship (i.e., pets), service (i.e., enabling an individual to live more independently), therapeutic assistance, and high-risk teams (e.g., search and rescue, dog-sled teams, law enforcement, and military operations) (Helton, 2009; Finkel, 2012). Similar to the determination of robotic roles, animals are chosen to fulfill different roles based on their natural abilities, characteristics, and functional capabilities (e.g., a horse for riding, a carrier pigeon for long-distance communication, a dog for personal companionship). Animals are highly valued in these partnerships because they are able to replace or augment human skills (e.g., guide dogs for the blind, sled dogs). Animals are also more capable than humans are in some areas, which is why humans continue to use them.

As Hens (2009) notes, "domestication becomes possible in the context of trust" (Hens, 2009, p. 6). Trust (or understanding the design capabilities) is essential for building effective interactions between entities, and it involves two separate notions: (1) knowing how a partner

*Roomba is a trademark of iRobot Corporation.

will respond, and (2) trusting one's self to interpret a partner's behavior. In human-animal relationships thus, a human needs to trust that their animal partner will do the task they were trained to perform. However, the human must also trust that at times, the animal will act like an animal, displaying tendencies and behaviors that are based upon its instinctive reactions. For example, according to the human-horse mutual trust paradigm, a rider must trust their horse to protect them while mounted. They also have to understand that their horse could break from their predictable role and "act like a horse," shying away from the owner, galloping off, or responding to a frightening stimulus (Keaveney, 2008). Like any relationship, human-animal trust entails risk and uncertainties (Ingold, 1994) because the human is not always absolutely sure how the animal will respond, or indeed vice versa. Therefore, a productive relationship between humans and animals depends on cooperation and mutual trust (Oma, 2010). Trust is evident across many areas of human-animal interaction (e.g., sheering sheep, milking cows, using a shire horse for plowing, hunting with dogs, or having a dog corral animals).

1.3 Animals and Robots

At a cursory glance, trust in human-animal interaction appears to share some characteristics with trust in human-robot interactions. These two types of relationships are similar because the purpose of both is to extend human skills and abilities in order to better accomplish a particular task (Bruemmer, Marble, and Dudenhoeffer, 2002). Additionally, the roles that each entity fills depends on its capabilities, skills, and affordances. For example, we would never consider using a cheetah for human transportation, as we would a horse. In fact, an animal's innate characteristics and our perceptions of the nature of the human-animal partnership are often taken into account in the design of numerous robotic systems.

Animal characteristics and behaviors have been emulated in multiple aspects of technology. Physical appearance, such as bird-like wing structures, can be found on modern day aircraft. The behaviors of bees, birds, and ants supply the underlying computer architecture for modern robotics and computer programming (e.g., Boyd's flocking model, ant colony optimization). Several existing robots are designed to look and/or behave like animals (e.g., zoomorphic, such as *AIBO*) (Coeckelbergh, 2011), primarily to evoke certain responses from humans or for task or physical environment functionality. Many robotic animals act as pets, companions for therapy, and entertainment (e.g., *Paro*) (Melson et al., 2009a). Others employ animal-inspired architecture to navigate in certain terrains and add to functionality. For example, *BigDog* is a legged robot designed to function essentially as a pack mule and traverse terrain not accessible by wheeled or tracked vehicles (Raibert et al., 2008). Our understanding of these and other human-robot interactions can be improved by drawing comparisons with human-animal partnerships (Coeckelbergh, 2011).

Although technology attempts to emulate the physical, behavioral, and cognitive aspects of biological entities, robots are not perfect copies of their biological counterparts. While studies have found that humans tend to describe their relationships with robotic animals as similar to

those with biological animals, the pattern of interaction with the robot is different than observed behavior with a live animal (Kerepesi et al., 2006; Melson et al., 2009b). A human's trust in a robotic animal may be superficially similar to human trust in a biological animal, yet preference for interaction with a biological animal rather than a robot has been demonstrated in children (Melson et al., 2009b; Pepe et al., 2008). This finding may be due in part to perception of the entity with which the human must interact. Additionally, trained animal behavior can be undermined by instinctive behavior in particular circumstances, whereas robots do not possess the same internal survival mechanisms. Therefore, while animals and robots share some characteristics in their interactions with humans, there are some significant differences in how humans perceive animals as opposed to robots. Consequently, can relationships between humans and animals adequately reflect human-robot relationships? Deeper exploration of human-animal partnerships is needed to determine the appropriate use of this analog.

1.4 Current Work

Robotic designs have attempted to imitate different features and characteristics of animals, which can subsequently impact how a human interacts with the robot. In this respect, perceptions of the human-animal interaction certainly play a large role in HRI. However, is the process of trust development and maintenance similar in these two domains? Is the assumption that human-animal trust parallels human-robot trust empirically supported? The purpose of this report is to review the current evidence relating to trust in human-animal partnerships and to compare these findings with our prior research on HRI trust, which led to the development of a three-factor descriptive framework of trust in robots (Hancock et al., 2011b, see figure 2). Our findings revealed that to date, research has demonstrated the great importance of robot performance and attributes in the development of trust in HRI (Hancock et al., 2011b). Environmental characteristics (e.g., team collaboration, task type) were also found to influence trust in HRI, to a lesser degree. Further, our findings revealed that human-related factors do not play a large role in the development of trust, although it is important to note that there is very limited empirical research available regarding human-related dimensions and their influences on trust in robots. Identifying factors that can impact trust between humans and animals could significantly increase our understanding of the human-animal partnership and its applications to HRI.

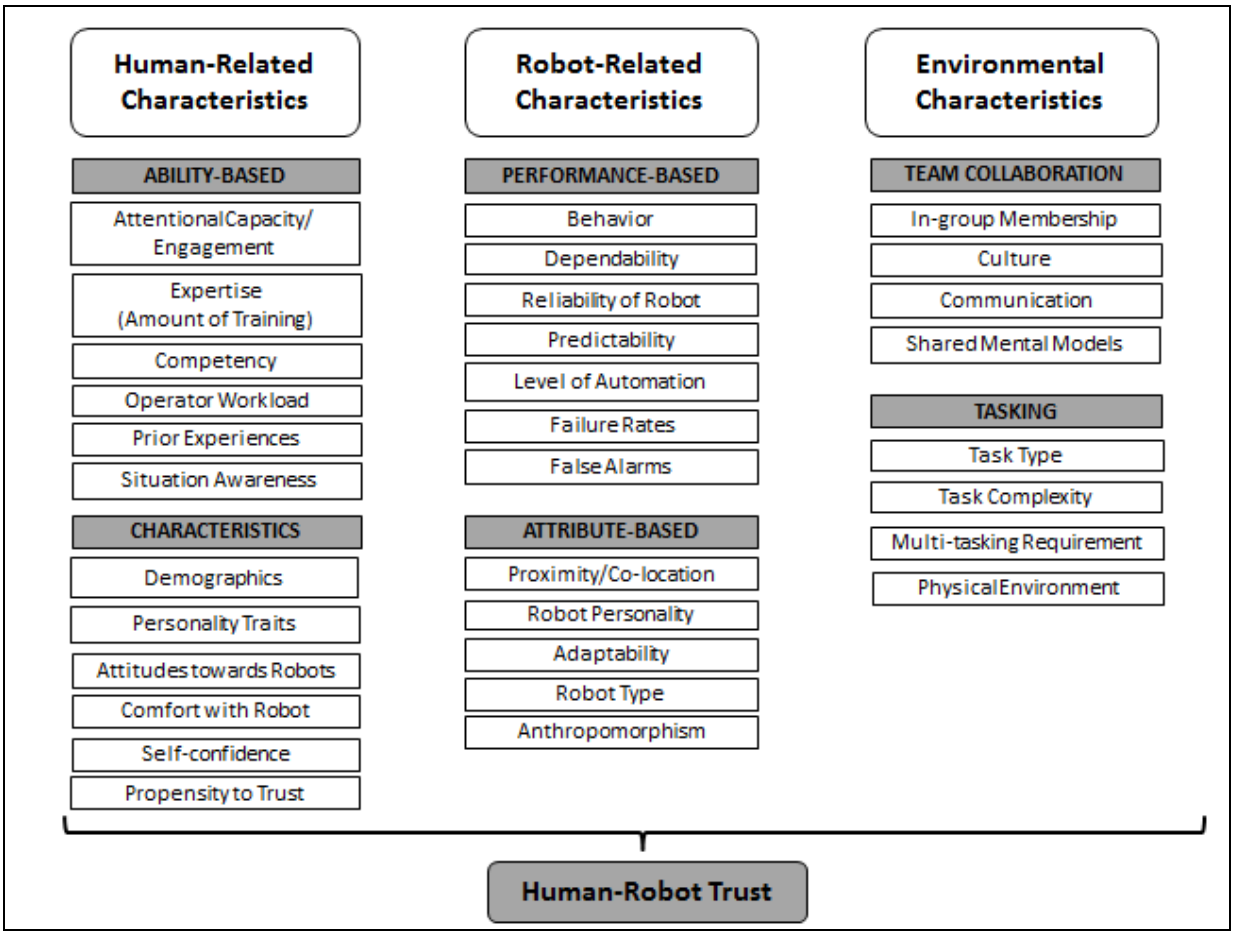

Figure 2. Three-factor framework of trust includes human-related, robot-related, and environmental characteristics associated with the development of trust in HRI. Factors were identified based on existing empirical and theoretical literature and input from subject matter experts (Hancock et al., 2011b).

2. Analytical Method

2.1 Sample of Studies

A review of empirical and non-empirical articles dealing specifically with human-animal trust was conducted using *Web of Science* database using *human*, *animal*, and *trust* as the primary search terms. The terms *dog, dependence*, and *reliance* were used as secondary search terms. We also used *Google*[*] and its derivative *Google Scholar*[†] to perform searches for the search terms. Initially, these searches yielded a total of 166 articles. Upon closer inspection, a majority of these documents were deemed inappropriate, as they focused on funding organizations

[*]Google is a trademark of Google, Inc.

[†]Google Scholar is a trademark of Google, Inc.

(referred to as "trusts"), animal welfare, animal testing, medical research, animal physiology, animal agriculture, and general human-animal interactions. Also, a number of articles investigated trust between humans, while some others focused on animal trust in other animals. Articles were included for analysis only if they included specific discussion of human-animal trust and/or quantitatively assessed trust (behaviorally or subjectively) in human-animal interaction.

After an initial listing of articles was obtained, the reference lists for these works were reviewed to determine whether any other related studies could be identified. This entire process resulted in 21 articles and one book chapter published between 1994 and 2010 (these sources are represented by asterisks in the References). Empirical and qualitative studies, as well as non-empirical (theoretical) reports, were collected. Frequently, trust was only mentioned (and not emphasized) in a majority of these studies. In fact, trust was often not the focus of research, but rather a subsidiary measure. The collected literature focused primarily on human-pet and horse-rider relationships (see table 1). For more detailed descriptions of the included human-animal literature, see the appendix.

Table 1. Existing human-animal research discussing trust.

Literature Topic	Citation
Empirical and Qualitative Literature	
Pet relationships	Beck and Madresh, 2008 Zasloff, 1996
Training dogs, human interaction	Greenebaum, 2010
Companion animals/pets	Brown, 2007
Horse-rider	Keaveney, 2008 Yorke, Adams, and Coady, 2008
Comparison of robotic dog to live dog	Pepe et al., 2008 Melson et al., 2009b
Officer-police dog relationship	Sanders, 2006
Human-baboon encounters in the wild	Smuts, 2001
Sled-dog and human partnerships	Kuhl, 2008
Dogs in animal-assisted therapy	Wesley et al., 2009
Non-Empirical Literature (Theoretical)	
Evolution and history of human-animal relationships and social morality	Allen and Bekoff, 2005 Ingold, 1994
Human attitudes towards animals in literature and emotional identification	Beierl, 2008
Evolutionary origins of social morality	Bekoff, 2004
Possible therapeutic benefits of human-animal interaction for children	Fawcett and Gullone, 2001
Social contracts between humans and animals	Oma, 2010
Human-horse relationship	Robinson, 1999 Saslow, 2002 Whipper, 2000
Ethics of human-dog interaction	Hens, 2009

2.2 Qualitative Analysis

Due to the dearth of empirical studies that focused specifically on and measured trust in the area of human-animal interaction, a qualitative analysis was deemed most appropriate for examining the collected research. Factors associated with trust in human-animal relationships were identified in the empirical and non-empirical collection. Following the trust framework developed in our previous research (Hancock et al., 2011b), we categorized these factors as human-related characteristics, animal-related characteristics, and environmental characteristics (see figure 3). The human-animal trust framework represented here will be further described in subsequent discussion. Several human-related characteristics associated with the development of trust were identified in human-animal interactions, including: prior experience, situation awareness, and the amount of training received before to the interaction. The identified animal-related characteristics included: animal behavior, predictability, performance, proximity, and anthropomorphism. Identified environmental factors were communication and level of uncertainty involved in the interaction.

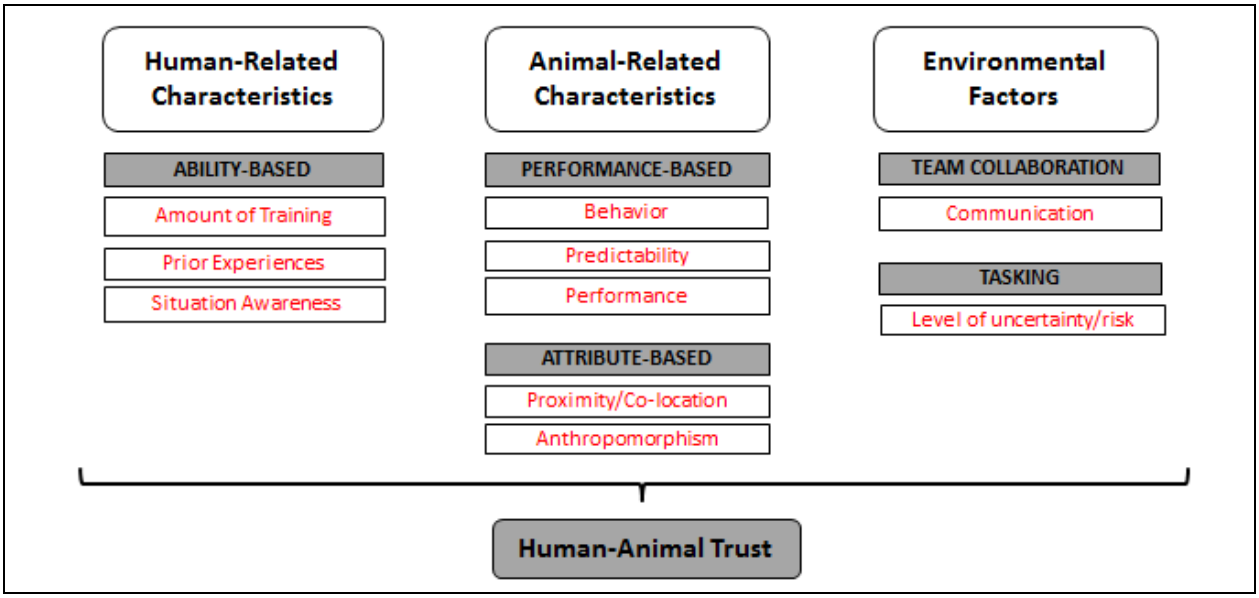

Figure 3. Identified factors associated with trust in human-animal interactions.

3. Results

3.1 Human-Related Factors Associated with Human-Animal Trust

According to Wilson (1994), past experiences with animals serve as indicators for the possibility of future relationships. If experiences were largely positive, the likelihood of future interactions with the same, or similar, animals may be greater than if experiences were predominately

negative. These prior experiences were found to be related to trust in animals. For a successful partnership to occur, humans must spend time with their animals each day, thereby enabling them to predict how that animal will react to most situations; this is crucial to the development of an understanding of the animal (Robinson, 1999). Trusting an animal's behavior can be advantageous to the interaction, but unfortunate injury and possible death can occur in situations where the human places too much trust in an animal without considering that ultimately the animal will act like an animal. For instance, in 2010 a killer whale named *Tilikum* tragically killed its trainer during a *Sea World* show (Schneider, 2010). This disaster served to remind people that the behavior of animals is not always predictable, even when an individual has interacted with an animal on a daily basis for a continued length of time.

Situation awareness also appears to play an influential role in the development of trust, in that it is important in determining or predicting the behavior of the animal in different circumstances. For instance, a dog handler must continuously be aware of the potential dangers in the environment as well as the animal's obedience and predictability in those different scenarios where danger is involved (Sanders, 2006). How will the animal behave in normal operating conditions as opposed to conditions that pose real or imagined threats? The human must be aware of the situations and of the particular contexts that can cause an animal to act instinctively and against what it has been trained to do.

Finally, the amount of training a human and their animal partner undergo before interacting can impact trust in the human-animal relationship. For a respectful partnership to develop between people and animals, both the human and the animal partner should be trained appropriately (Greenbaum, 2010). The amount of training horse owners have with their horses influences their ability to relate with and trust the horses (Keveaney, 2008). More time spent interacting with the horses corresponds to more trust and understanding of them. This may also be the case with human-animal partnerships with pets, service animals, etc. For example, it has been demonstrated that consistent interaction with a therapy animal can lead to the development of trust in that animal, which can then transfer (over time) to interactions with people (Wesley, Minatrea, and Watson, 2009).

The amount of training, prior experience, and situation awareness are all important trust antecedents that are shared by human-animal and human-robot interactions (see figure 3). However, attentional capacity, competency, workload, human demographics, human personality traits, attitudes towards animals, comfort with animals, self-confidence, and propensity to trust were factors identified in the human-robot literature but not clearly described in the human-animal research. Though these factors are not specifically cited in the animal literature, we believe they are still relevant in terms of human-animal trust. For example, the competency of the human handler and their attitudes towards their animal partner can impact trust in the animal, as well as the effectiveness of the interaction. Thus, the animal and robot domains may have more human-related commonalities than are investigated in the animal literature, to date.

3.2 Animal-Related Factors Associated with Human-Animal Trust

The performance-based characteristics of the animal include the closely related factors of animal behavior, predictability, and overall performance (see figure 3). A human's tendency to trust a biological animal mainly depends on whether the animal can behave and follow directions. However, humans will still hold predisposed mistrust against the animal, no matter how much the animal has been domesticated or trained (Keaveney, 2008). In other words, even though their experiences with animals can be positive, humans still hold beliefs that animals will exhibit behavior characteristically associated with that particular animal (e.g., a horse will act like a horse and bolt). Behavior predictability allows a human to trust the certain behaviors will be evident during the interaction. Finally, in terms of performance, trust can be influenced by the ability of the animal to follow instructions given by the human (Pepe et al., 2008). For instance, a dog that does not obey human commands likewise does not instill a high degree of trust in the human.

While performance of the animal during the interaction can impact trust, the attributes of the animal can also contribute to the levels of trust a human has in the animal (see figure 3). The animal attributes identified in the extant literature include: proximity/co-location and anthropomorphic characteristics. Research has demonstrated that close physical proximity is important in building lasting trust between horse and rider (Keaveney, 2008). In fact, some riders have felt resentment when having to share their horse with others and are forced to give up that physical closeness (Robinson, 1999). Co-location has also been found to have an emotional effect on people interacting with domesticated animals, especially dogs and cats. Closeness allows pet owners to feel safe and comforted (Zasloff, 1996), which can in turn influence trust development. The anthropomorphic characteristics of animals (i.e., the attribution of human characteristics, including physical appearance, to an animal) have also been found to impact trust. Research has demonstrated that people use the appearance of an animal (or other entity) to assign that entity initial attributes, regardless of whether the attributes match the true characteristics, behaviors, and capabilities of the animal (Ellis et al., 2005). Additionally, some domesticated animals (e.g., cats, dogs) are specifically bred to produce 'cute' traits to facilitate instantaneous human-animal bonds that offer unconditional love and trust (Keaveney, 2008).

The collected work from the human-animal trust domain document animal behavior, predictability, performance, proximity, and anthropomorphism as factors influencing the development of trust in human-animal partnerships. These factors are also evident in human-robot trust development. Additionally, the human-robot literature indicates that robot dependability, reliability, level of automation, failure rates, false alarms, and transparency can affect human trust in the robot. The robot's personality, adaptability, and type can impact this trust as well. While these identified robot-related trust factors have not been explored in the animal literature, they may directly correspond with animal characteristics that can influence trust in human-animal interactions. For example, failure rates demonstrated by a robot parallels

the instances when an animal reverts to instinctual behavior instead of adhering to trained behavior. Also, the level of automation is certainly a characteristic of machines, but it corresponds with the amount of control that a human feels they have over an animal partner. Thus, we may conjecture that many of the robot-related characteristics may parallel human-animal relationships.

3.3 Environmental Factors Associated With Human-Animal Trust

In examining the human-animal trust research, the quality of communication and the amount of risk involved in the physical environment were environmental factors found to impact the trust a human has in an animal (see figure 3). Communication requires both the transfer of information from one partner to another partner and the use of commands and requests to gain additional information when needed. A joint understanding of this communication is unique to each human-animal partnership, in part due to the fact that each animal has a distinctive quality or style of expression, and each human can interpret that expression differently. Therefore, mutual trust can only occur after an established means of communication and respect between the two entities has been developed. Two way communication with the animal is very important; a human must understand and interpret the animal, as well as possess the ability to communicate commands effectively to the animal (Kuhl, 2008). This pattern of communication often utilizes behavioral cues and body language. For example, in a race, the horse and rider have to work cooperatively and trust each other to the fullest extent sharing a common goal (the finish line). The rider uses his legs and body to communicate commands to the horse. In addition, dog handlers and trainers believe that it is critical to understand how to communicate with and read the dogs in order for mutual trust to develop (Sanders, 2006). If a trainer does not understand a dog, he/she will not be able to depend on the dog, thus making the trust development process a futile one. Conversely, if the animal trusts the human, the animal will be more confident, perform its task better, and be more willing to do challenging tasks (Kuhl, 2008).

The amount of risk present in the environment can impact the trust a human has in an animal partnership. Trust plays the greatest role in contexts where there are high levels of uncertainty and risk and a lesser role in situations that are nonthreatening and predictable (Miller, 2005). In effect, the type of human-animal partnership will likely dictate the levels of risk involved in the interaction. As such, the role of trust in a human-pet relationship is much lower (due to the low amount of risk involved) than the trust involved in a human-animal interaction occurring in a dangerous (e.g., riding a horse) or life-threatening environment (e.g., sub-zero temperatures) due to high levels of uncertainty and risk. For example, dogsled patrols require humans to rely on their dog-team in highly remote Arctic locations where hunger, life-threatening injuries, exhaustion, frostbite, and threats from predators are extremely likely (Finkel, 2012). Further, the extent to which a human must rely on an animal in order to perform specific tasks or to extend the capabilities of the human (e.g., guide dog for the blind) can impact the degree of trust the human must have in order to interact most effectively. Essentially, the riskier the situation is, the

more important human-animal trust becomes, as sometimes a human must rely solely on the decisions of their animal partner (e.g., sled-dog and human partnership during a bad storm in a secluded area; Kuhl, 2008).

Communication between team members or partners is important in both human-animal and human-robot collaborations. The level of uncertainty and risk (which was cited as a factor involved in human-animal trust) was not explicitly highlighted in the human-robot literature. It is important to note, however, that this factor was implicitly assumed in many of the definitions of trust (Lee and See, 2004). Conversely, the human-robot trust research has identified in-group membership, culture, shared mental models, task type, task complexity, multi-tasking requirements, and physical environment to be important antecedents of human trust in robots (Hancock et al., 2011b).

Although there is no known documented empirical or theoretical support for these specific factors in the human-animal research to date, their relevance can be reasonably conjectured. For example, the type of animal used for certain tasks can be *culturally dependent* (e.g., transporting people or equipment via elephant versus horses), and *in-group membership* can play an important role in determining trust between humans and animals, e.g., an animal considered to be a family member or a teammate is treated (and trusted) differently than other animals outside of those familiar circles. Further research is needed to explore how these team collaboration and tasking characteristics can impact trust in the human-animal partnership.

4. Discussion

While the collected research discusses different factors associated with trust, the process of trust development in human-animal partnerships is not thoroughly investigated nor fully supported empirically (i.e., much of the efforts have been theoretically-based or anecdotal). Findings from our qualitative analysis suggest that human trust in biological animals has several similarities with human trust in a robot. In both contexts, trust referent (i.e., animal, robot) predictability, performance, proximity, and anthropomorphic characteristics seem to play important roles in the development of trust. In addition, a human's prior experiences, situation awareness, and amount of training are associated with trust in both human-robot and human-animal interactions. Furthermore, the environmental variables of communication and level of risk appear to have important implications for human trust with both robot and animal relationships.

Nonetheless, there are distinctive and sometimes conflicting differences between these two types of relationships. Animals (including humans) have an innate sense of self-preservation, which at times undermines their trained behavior. Conversely, robots do not have instinctive behaviors; they act based on the intentions of the designer. However, humans tend to have more positive

biases towards unfamiliar entities, which leads them to have unrealistically high expectations for objects such as machines, automated systems, and robots (Madhavan and Wiegmann, 2007). People are much more forgiving of human error (and perhaps animal errors as well) than they are of machine or robot errors. On the other hand, Sung et al. (2007) reported that many Roomba users they interviewed did not expect their robot to work flawlessly and were willing to take on extra work to enhance the robot's performance (e.g., tidying the room before cleaning). Therefore, while some of the factors impacting trust between humans and animals can be applied to human-robot interaction, the results are sometimes conflicting.

4.1 Implications for Future Research

Several areas needing further research were identified for both the human-animal and human-robot domains. First, training in human-animal partnerships and how those approaches can extend to HRI should be explored. Training in human-animal partnerships involves many different aspects, including but not limited to: (1) training of the animal itself in order for it to learn appropriate tasking and behaviors, (2) training the human handler to interact with the animal, and (3) training the handler to accurately interpret the behaviors of the animal. Based on the human-animal trust literature, training for behavioral predictability and communication efficiency are key aspects that can influence trust in the human-animal interaction. For example, service dogs are molded to behave predictably, so that their handlers can trust their dependability; likewise, handlers must demonstrate certain characteristics to ensure that the trusting relationship works efficiently (Sanders, 2006). However, the handler must also take into account the potential risk of trusting the dog, as the dog can break from his/her predictable role and act in a potentially dangerous manner. This special bond facilitates the development and maintenance of trust and understanding in the human-dog relationship. Training can also serve to facilitate the effectiveness of two-way communication between animal and human partners. For example, through training, horse owners are able to teach their horses to understand and obey the human's commands and behavioral cues (Saslow, 2002). This can be done by consistently showing the horses that negative outcomes do not occur when they follow the human's lead, even in situations of uncertainty. Likewise, horse owners should be sensitive to signals and cues given by their horses to ensure trust is maintained in both directions. Trust becomes very important because successful interaction between human and animal leads to effective task completion. Investigating the types and methods of training animals successfully and determining whether this translates to HRI can be potentially very useful.

Second, both human-animal and human-robot domains focus very little on the notion of mental models, which has been shown to be extremely important in human teams (Cannon-Bowers, Salas, and Converse, 1993). Shared mental models enable humans to manage and adapt their behaviors to difficult and changing task conditions, which can impact team processes and performance (Mathieu et al., 2000). Several different types of mental models exist, which are all critical to team functioning. These include: (1) models of the equipment or tools needed to

perform the tasking (e.g., how to operate equipment, likely failures, and limitations); (2) models of the task itself (e.g., the procedures involved, contingencies, strategies, probable scenarios, and variables in the environment); (3) models of how the team members interact with each other (e.g., team member roles and responsibilities, patterns of interaction and communication, and knowledge of role interdependencies); and (4) models of the team (e.g., knowledge of each team member's knowledge, skills, abilities, preferences, and tendencies; Cannon-Bowers, Salas, and Converse, 1993). Essentially, sharing accurate mental models across teammates allows predictions to be made about team members' behaviors (Mathieu et al., 2000), and being able to better predict behavior can influence the level of trust a human has in his/her animal counterpart. Examining how shared mental models can impact trust in animal and robot partners, as well as how the models can be manipulated through training, are important considerations for future research efforts (Fincannon et al., 2011).

4.2 Conclusion

Although limited research in the human-animal literature deals specifically with trust development between humans and animals, theoretical and anecdotal evidence suggests that several human, animal, and environmental characteristics are associated with trust. The limited research in this area reveals that while human-animal interaction is a necessary and desirable part of many people's daily routines, less attention is given to the constructs that assist in ensuring that effective interaction takes place. As we continue placing human-animal teams in more risky and uncertain environments, the importance of studying the components contributing to success will be ever vital. We predict that the construct of trust will continue to emerge as one of the more powerful predictors of human-animal team interaction; empirical research is expected to support this claim. Based on the current evidence, several aspects of trust in human-animal interaction appear to be good analogs for human-robot trust. This is especially important to consider as robots continue to emulate animal characteristics and even supplant animal partners in some cases.

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Appendix. Description of Human-Animal Studies Included in Qualitative Analysis

Table A-1. Description of human-animal studies included in qualitative analysis.

Citation	Human Component/ Participant	Animal(s) Involved	Specific Measures Used (if any)	Type of Research	Brief Summary/Major Finding(s)
Allen, C., and Bekoff, M., 2005	Evolutionary roots of human nature	Group-living mammals	NA	Theoretical review	Evolutionary origins of morality (and trust, among other things) is examined by focusing on how animals living in groups behave socially.
Beck, L., and Madresh, E. A., 2008	Pet owners	Dogs and cats	Relationship Questionnaire and the Avoidance and Anxiety scales from the Experiences in Close Relationships-Revised questionnaire.	Survey-based research	Participants' reports of their relationships with pets and with romantic partners were compared. Ratings correlated very little with each other; pet relationships were more secure (i.e., characterized by trust) than romantic relationships.
Beierl, B. H., 2008	Readers/ writers of fiction	Animals found in fiction literature	NA	Theoretical review	Investigates human attitudes toward animals, as described in the existing body of fiction literature. Animal-centric literature has positive emotional and moral effects and tends to emphasize compassionate human-animal relationships.
Bekoff, M., 2004	Evolutionary roots of human nature	Group-living mammals	NA	Theoretical review	Discusses the evolutionary roots of morality, including trust and cooperation.
Brown, S., 2007	Owners of companion animals	Horses, dogs, cats, rabbits	Interview questions relating to the companion animal and its relationship with the human.	Structured interviews	Self objects help a human build a sense of self. Animals were found to rival or even surpass humans in their ability to provide self object needs.

Table A-1. Description of human-animal studies included in qualitative analysis (continued).

Citation	Human Component/ Participant	Animal(s) Involved	Specific Measures Used (if any)	Type of Research	Brief Summary/Major Finding(s)
Fawcett, N., and Gullone, E., 2001	Children with physical, emotional, or mental limitations	Non-human animals	NA	Theoretical review	Examines the possibility of incorporating animals into therapy treatments for children. This paper calls for empirical investigation in this area due to the suggested benefits of human-animal interaction for children.
Greenebaum, J. B., 2010	Dog trainers and their methods	Dogs	NA	Observations and review	Two methods used to train dogs are investigated: a dominance-based method (i.e., the dog is treated as a subordinate), and a reward-based method (i.e., promotes companionship).
Hens, K., 2009	Companion animal owners	Companion animals/dogs	NA	Theoretical review	Different ways to perceive companion animals are explored, and the ethical duties that society has towards the care of animals is outlined.
Ingold, T., 1994	Hunters and gatherers in the context of evolution of the human-animal relationship	Domesticated and un-domesticated animals	NA	Theoretical review	Offers a historical perspective of the evolution of human-animal relationships. Discusses domestication of animals to serve particular purposes. The author opines that this evolution involves a transition from trust to domination.
Keaveney, S. M., 2008	Horse riders with varying levels of experience	Horses	Questionnaires with probing questions.	Survey-based research, interviews, and participant observations.	Relationships with horses were compared with pets. Shared themes include viewing the animal as a friend and a provider of emotional support. Divergent themes include the feeling of conditional love—pet owners say their pets give them unconditional love, but horse owners have to earn their horse's trust and love. Other related themes are outlined in the text.

Table A-1. Description of human-animal studies included in qualitative analysis (continued).

Citation	Human Component/ Participant	Animal(s) Involved	Specific Measures Used (if any)	Type of Research	Brief Summary/Major Finding(s)
Kuhl, G., 2008	Sled-dog owners	Sled-dogs	Interviews with dog-sled mushers (i.e., handlers).	Structured interviews	Explores the musher-sled dog relationship. Several aspects of building the relationship were identified as important: getting to know the dogs, two-way communication, trust, partnership, and experiences with the dogs.
Melson, G. F., Kahn, P. H., Jr., Beck, A., Friedman, B., Roberts, T., Garrett, E., and Gill, B. T., 2009b	Children	Australian Shepherd dog and the Sony AIBO	Observation of child's interactions and structured interview, and a card sort task (e.g., is AIBO more like "object A" or "object B").	Experimental	Examined how children interacted with a live dog as opposed to a robotic dog (AIBO). Children spent more time in physical contact with the live dog. A majority of children described both the live dog and AIBO as having mental states, morality, sociality, etc. Children were likely to give both "dogs" commands.
Oma, K. A., 2010	Hunters and gatherers in the context of evolution of the human-animal relationship	Domesticated and un-domesticated animals	NA	Theoretical review	Critiques Ingold's (1994) assertion that hunters treat their prey differently (e.g., like brothers in that there is trust and reciprocity) than farmers treat their domesticated livestock (e.g., like slaves and unable to reciprocate). Instead, the author supports the idea of a social contract between humans and animals.
Pepe, A. A., Ellis, L. U., Sims, V. K., Chin, M. G., 2008	College students, most of whom owned pets	3-year-old Boston Terrier and the Sony AIBO	Mood Rating Scale; Overall Evaluation; Attributions Questionnaire (including untrustworthy/trustworthy scale); Demographics Questionnaire.	Experimental	Explored differences in interaction with a robotic dog (AIBO) versus a live dog. The dog was rated as significantly more trustworthy than the AIBO.
Robinson, I. H., 1999	Horse owners and riders	Horses	NA	Theoretical review	Discusses the historical impact of the horse-rider relationship. Examines the costs and benefits of these types of relationships.

Table A-1. Description of human-animal studies included in qualitative analysis (continued).

Citation	Human Component/ Participant	Animal(s) Involved	Specific Measures Used (if any)	Type of Research	Brief Summary/Major Finding(s)
Sanders, C. R., 2006	Police K-9 trainers/handlers	Police K-9 dogs	NA	Based on ethnographic fieldwork	Discusses the differences involved in treating a K-9 police dog as a weapon versus as a companion or family member. Emphasized the training methods employed by handlers and the importance of trusting the police dogs in dangerous situations.
Saslow, C. A., 2002	Horse trainers/owners	Horses	NA	Theoretical review	Explores the field of equine perception, the visual system, and the process of cognition in horses. Discusses how touch is the primary form of communication between horse and rider, and how understanding how a horse perceives things can facilitate the creation of a human-horse partnership.
Smuts, B., 2001	The author's experiences with human-animal bonds	Baboons and dogs	NA	Personal observations	Describes the author's experiences with wild baboons and how trust was gradually developed throughout the course of the interaction. The author's relationship with her dog was also explored.
Wesley, M. C., Minatrea, N. B., and Watson, J. C., 2009	Adults seeking substance abuse treatment	Therapy dog	Demographics questionnaire; Pet Attitude Scale; Helping Alliance Questionnaire Revised	Experimental	The effectiveness of animal-assisted therapy was examined. Findings revealed that the addition of a therapy dog complements the existing therapy approaches, as the participants in this group felt the treatment was a more positive experience than those in the control group.
Whipper, A., 2000	Horse-riders	Horses	NA	Theoretical review	Evaluates the process of building a horse-rider partnership, including the aspects of compatibility, respect, trust, confidence, and communication.

Table A-1. Description of human-animal studies included in qualitative analysis (continued).

Citation	Human Component/ Participant	Animal(s) Involved	Specific Measures Used (if any)	Type of Research	Brief Summary/Major Finding(s)
Yorke, J., Adams, C., and Coady, N., 2008.	Adults who had a therapeutic relationship with a horse following a trauma	Horses	Interview asking question relating to the horse-rider relationship during trauma recovery.	Semi-structured interviews and behavioral observations.	Investigated therapeutic riding programs and their effect on recovery from trauma. Findings showed that these human-equine relationships contributed significantly to the human's recovery from trauma, which in some ways parallels a therapist-client relationship.
Zasloff, R. L., 1996.	Pet owners	Dogs and cats	Comfort from Companion Animals Scale.	Survey-based.	A scale for measuring attachment to companion animals was examined. The importance of considering species-specific behavior when assessing human-animal interaction is highlighted.

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